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Agent Oriented Construction of a Digital Factory for Validation of a Production Scenario

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Abstract

At present, there are various types of manufacturing systems from the traditional centralized system to the autonomous distributed system which has high flexibly for changes in the kinds and/or amounts of products. To support production planning for such a variety and, as a result, to prepare an adequate production scenario which can be well reviewed not only from an economical but also from an environmental view, IT support tools are necessary. In this paper, an agent oriented digital factory is proposed as an IT support tool for production planning. A trial implementation of the digital factory is also reported.

Keywords: Virtual manufacturing; Multi agent system; Digital factory; Production planning; Machine model; Product model

1. Introduction

In recent days, factories for mechanical products are built or located not only domestically but also outside the country. Also, the variety of manufacturing style is very large, from the traditional centralized system for high-volume production to the autonomous distributed system for a high-mix, very-low-volume production or a high variety of kind and volume production. When considering the above situations, it is expected to have IT support for generating a proper production scenario [1].

CAD/CAM/CAPP systems have been used to support traditional centralized controlled manufacturing systems. On the other hand, the introduction of a new concept and methodology is needed to support process planning for autonomous decentralized manufacturing systems [2]. There have been several attempts. One example is the holonic manufacturing system [3] [4] [5]. In this system, a manufacturing activity unit such as a machine tool, assembly machine and/or AGV is configured as a holon. Multi-agent technology is also being well applied for this type of manufacturing system [6]. A manufacturing activity unit is also configured as an agent. To obtain more flexibility and autonomy, authors have proposed an event driven configuration [7] [8]. The occurrence of an event means that a workpiece or parts for the product are input to the shop floor. Product, workpiece and assembled part are also configured as agents in addition to agents of manufacturing activity.

In this paper, it is defined that a digital factory is a virtual factory and an IT platform for supporting sustainable production planning by executing virtual manufacturing. In other words, in the digital factory, the production scenario is examined by simulating manufacturing processes. The above attempts provide useful knowledge to construct a digital factory. The requirements for system functions of a digital factory are as follows.

- Robust IT platform for simulation of various production scenarios, pre-assessment of various line configurations, and comparison of several production processes.
- Precise simulation from the machine view, process view and product view.

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- Support for generating a production scenario with less of production costs and environmental impacts.
- Easy input of machine configuration in the factory and information of manufactured products,
- Easy change of setting for the process and optimization parameters, and
- Graphical display of status in progress and the results from a factory view and a product view.

A configuration method of a digital factory to fulfill the above requirement is proposed in this paper. Planning of efficient operation and control for the manufacturing system would become possible by using this digital factory. In this digital factory, not only traditional centralized controlled manufacturing but also autonomous decentralized manufacturing would be virtually achieved to determine a better production scenario. Some test cases were examined on the prototype system.

2. Construction and use of the digital factory

2.1. Structure of a digital factory

To construct a virtual production line requires modelling an actual shop floor and its components, including their activities. Furthermore, these production lines should be able to be controlled by both a traditional centralized method and an autonomous decentralized method. Multi agent technologies are applied to modelling them. The lower part in Fig. 1 shows actual production lines. There are two lines: machining line and assembly line. The virtual production line mirrors the structure of the shop floor in the actual factory. In these lines, all components such as machine tools, assembly machines, robots and workers are configured as software agents. These agents are called "machine agent" in this paper. The upper part of Fig. 1 shows a virtual production line constructed by machine agents. In addition to these agents, manufactured products such as machined workpieces and assembled parts are also configured as software agents. These agents are called "workpiece/part agent". Workpiece/part agents lead and control execution of virtual production to finish themselves as a completed product.

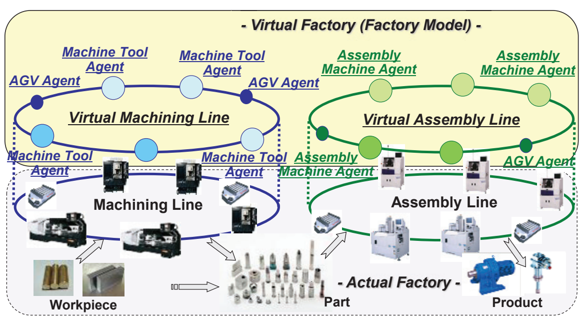

Fig. 1. Modeling of a factory

The digital factory is constructed on the above virtual production line. Fig. 2 shows the conceptual structure of the digital factory [9]. There are two panels which have a user interface. Two panels are plant panel and product panel. Panels have functionalities like a blackboard and a manager agent in a general multi-agent system. The operator of the digital factory can input production scenario, configuration of the shop floor, control policy for production line, energy saving plan and etc. through the user interface of the panel. The operator can also observe progression and results of virtual production through the user interface. The plant panel manages the configuration of a virtual production line such as creation of new machine agent and inactivation of a machine agent. The plant panel also monitors virtual production progress from the equipment/device view. The product panel controls the progression of virtual production by generation of workpiece/part agents. The product panel monitors virtual production progress from the product view.

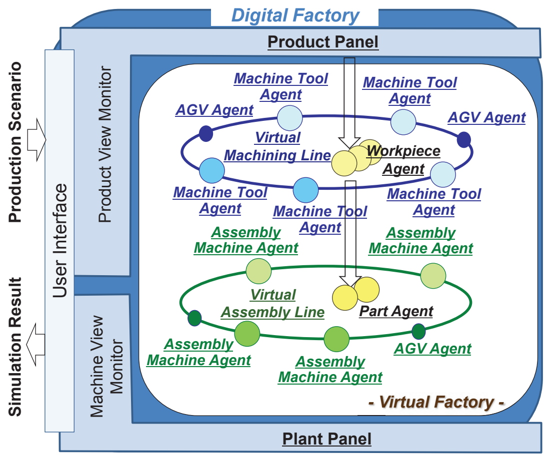

Fig. 2. Configuration of a digital factory

2.2. Validation process of a production scenario

A production scenario is input to the digital factory through a user interface through the above panels for validation. Usually, a production scenario is prepared by a process planner. A production scenario is validated by virtual production following the scenario. By repeatedly modifying and validating a scenario, a proper production scenario is selected from an economical point and environmental point of view.

Fig. 3 shows a structure of the production scenario. A production scenario is constructed from product data, which is a target of manufacturing, process, which is job sequences for producing the product, and rules and method for executing virtual production. Product data includes data of its component parts and workpiece data. Process consists of jobs which are executed on some resources. There are rules and methods such as methodology and optimized parameters of production line control, dispatching rules of scheduling and theory for machine allocations. A production scenario may be provided as an XML file.

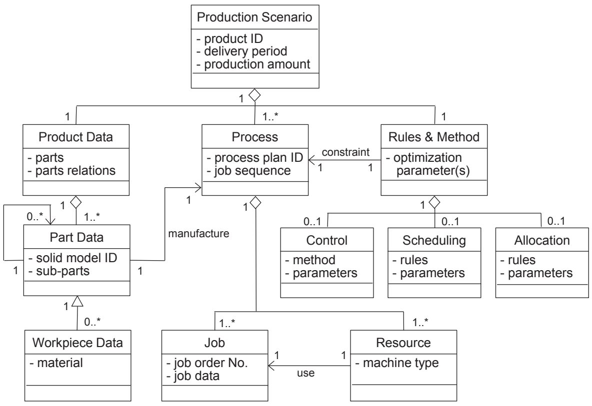

Fig. 3. Class diagram of a production scenario

A validation procedure in a digital factory is shown in Fig. 4. Before the validation procedure starts, a virtual production line configuration is done by the plant panel. According to the production scenario, the product panel creates workpiece/part agents with operation data to complete them as a product. When operation data indicates autonomous control, the first step of the validation procedure is that a workpiece/part agent requests job estimation to machine agents. A machine agent examines whether the job can be executed by itself and returns the estimated result of expected job start time. Second, after the workpiece/part agent receives the result from the machine agent, the workpiece/part agent selects a machine based on the earlier finishing time. Third, the workpiece/part agent allocates the job to the selected machine. When centralized control is taken, the validation procedure is started from this machine allocation according to the operation data. Forth, the machine agent adds the job requested by the workpiece/part agent to the end of the scheduled task list and returns a job execution starting time. Fifth, the workpiece/part agent requests an AGV agent to transfer virtual things such as material, mounted parts and tools to the machine for virtual execution of the job. Last, during execution of the virtual operations in the machine agent, the machine agent reports the condition and status to the workpiece/part agent. The workpiece/part agent sends the report to the product panel.

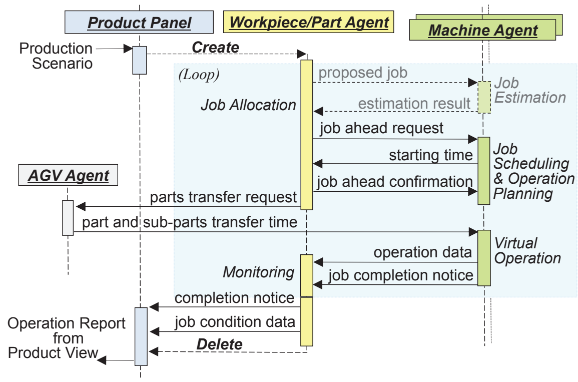

Fig. 4. Validation procedure in the digital factory

3. Modeling of a production Line

3.1. Plant panel

The plant panel shows the condition and configuration of machines which are used to manufacture products in a virtual production line. The plant panel also sets up the configuration of a virtual production line. Fig. 5 shows the detail of the plant panel. Initially, the configuration of the production line and details of component machines are provided and the plant panel sets up machine agents with machine model corresponding to the input configuration by using templates of the machine model. When executing virtual production, the operator could indicate active machines and non-active machines. When the configuration is changed, it is easily reflected by deletion/generation of machine agents. Templates are prepared to describe specification and capability of the machine by filling up the template. The template in XML is prepared corresponding to the machine type. The plant panel monitors the machine status on the virtual production line, collects operation data, productivity data and environmental data, calculates the total of the economical and environmental index by communicating with machine agents.

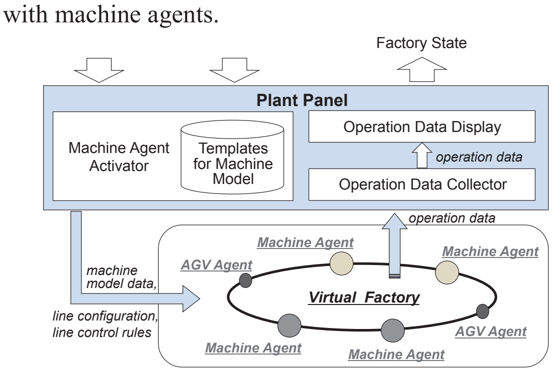

Fig. 5. Role of the plant panel

3.2. Machine model

The structure of a machine model is shown in Fig. 6. In the machine model, there are specification data of a machine, operations which the machine can perform, knowledge on how to operate processes, and knowledge on how to calculate cost related items and environmental indexes are described in the machine model. The machine model has a machine ID and machine type. Specifications include format type of operation commands and machine control data. Specification of the machine such as size, weight and speed are also described. Operation data has operation orders and its own operation conditions. Operation data consists of performed assembly operation types such as machining, screwing and bonding, using tools and jigs corresponding to the each operation, and the material handling method. The knowledge includes a mathematical formula for calculating values such as operation time and power consumption.

A machine agent has its own machine model. The plant panel has templates for machine models and fulfils an adequate template when setting a machine agent. The machine model is implemented using XML.

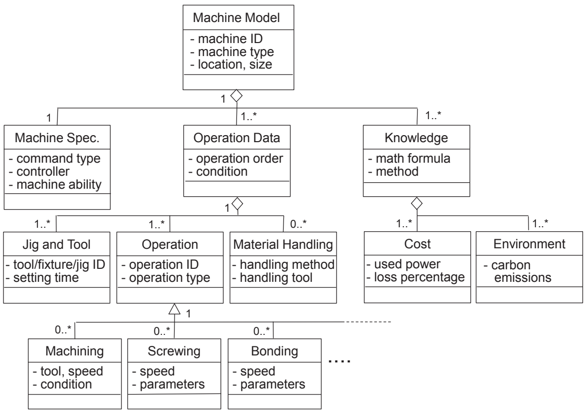

Fig. 6. Class diagram of a machine model in a machine agent

3.3. Machine agents

According to the configuration, machine agents are set by the plant panel. When setting a machine agent, the machine model and the operation rules are given. The general structure of a machine agent is shown in Fig. 7. When the workpiece/part agent asks whether a requested job can be performed by a machine, the job estimator in the machine agent determines which operations can be processed by the machine itself, checks its own schedule and replies with the possible operations and schedule. Once a job is allocated by a workpiece/part agent, the job scheduler and operation planner autonomously schedules and plans job operations. The command generator generates operation commands. Then, the virtual operation executer simulates controls and operations of the tasks, calculates productivity data and environmental data, and reports them to the plant panel and workpiece/part agent. The machine model is referred to at every stage in a machine agent.

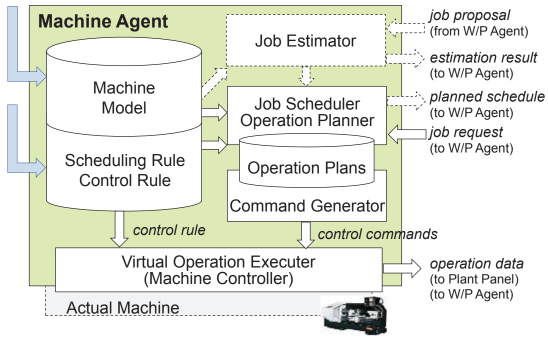

Fig. 7. Basic structure of a machine agent

4. Control of virtual production

4.1. Product panel

The product panel provides a user interface from the product view and functions corresponding to the product agent. The structure of the product panel is shown in Fig. 8. Manufactured product data such as parts structure, production amount and delivery period, and the process plan is input as a production scenario. A product model which is prepared using a CAD system is also provided.

The product panel works like a product agent. There are two functions. One is the generation of the workpiece/part agent with process model. By referring to the product data and production scenario, the process model generator produces a process model which describes details of the manufacturing processes. Then, the agent creator creates the workpiece agent for the part which is machined in-house. For assembly, the parts are categorized into a base part that forms the basis of the assembly operation and sub parts that are assembled with the base part. The agent creator also creates the part agent for the base part also by referring to the product data and production scenario. The other function of the product panel like a product agent is monitoring the progression and status of the workpiece/part on the virtual shop floor from the productivity and environmental views. The process monitor displays the workpiece/part status, collects environmental data and productivity data, and calculates an environmental index by communicating with workpiece/part agents.

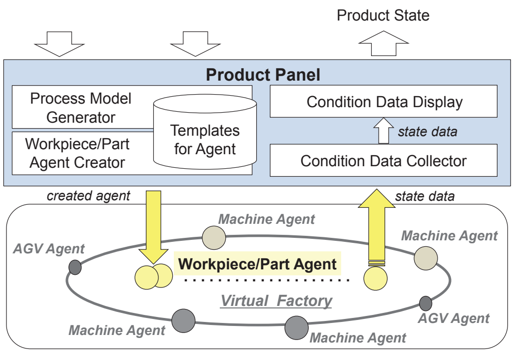

Fig. 8. Role of the product panel

4.2. Process model

The structure of a process model is shown in Fig. 9. Process type is divided into two types: machining and assembly. Machining process includes job sequences and target workpiece data. Each machining job includes information such as operation type, settings and file name of CL data. Assembly process includes job sequences and parts data. Sometime, an assembly job has a recursive structure which means a sub assembly process.

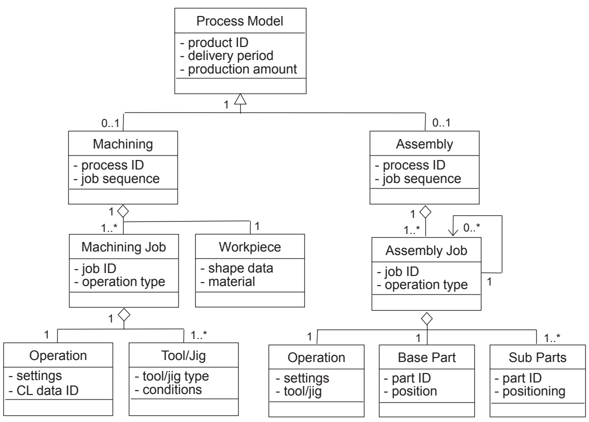

Fig. 9. Class diagram of a process model in a workpiece/part agent

4.3. Workpiece/Part agents

The workpiece agent with the workpiece data and the machining process model is created by the product panel when the workpiece is input to the machining line. The workpiece agent is deleted when the part is completed. The part agent with the part data and the assembly process model is created by the product panel corresponding to each process when a new base part is input to the virtual assembly line. The structure of the workpiece agent and the part agent are almost the same. Fig. 10 shows a basic structure of workpiece/part agent.

When the production line is operated by an autonomous decentralized control, the machine searcher determines which machine can proceed with the jobs and selects the machine by referring to the process model and communicating with machine agents. Then, the machine allocator assigns the job to the machine by referring to the job plan in the process model and communicating with machine agent, and requests the AGV agent to deliver itself, tools/fixture and the necessary mounted parts to the machine allocated to the job. The AGV agent calculates the transfer time. During the virtual execution of the job, the workpiece/part agent monitors workpiece/part condition, collects productivity data and environmental data, and reports them to the product panel.

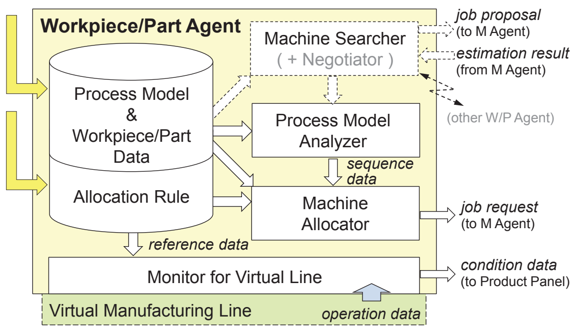

Fig. 10. Basic structure of a workpiece/part agent

5. Prototype system for autonomous assembly simulation

Trial implementation of the digital factory for assembly is developing using a commercially available multi-agent simulator "artisoc[10]." Autonomous decentralized assembly operations are simulated on this system. This system has three major functions: simulation manager, simulation monitor and virtual assembly factory.

One of applied examples is the assembly of mobile phones. Fig. 11(a) shows the production steps for a mobile phone. There are two types of mobile phones. The number of production steps depend on the type of mobile phone. A production line is modeled as shown in Fig. 11(b). The production line consists of several screwing machines, bonding machines and workers who can do both the screwing and bonding operations. The job is allocated autonomously and dynamically to the machines.

Figure 12 shows one of the user interface displays. Through this interface, the operator configures the production line by selecting machine and inputting parameters. The operator also inputs the production scenario such as product type, number of product, delivery time and production order. The display screen is changeable through the use of a tab. From various view points such as machine agent view and product agent view, simulation conditions in progress and simulation results can be monitored.

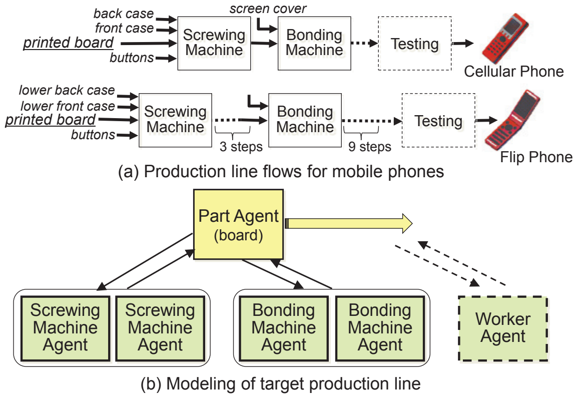

Fig. 11. Applied example -mobile phones-

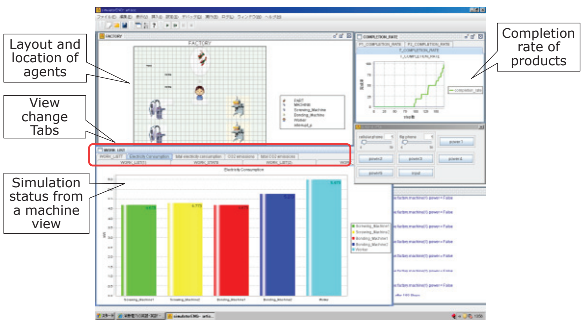

Fig. 12. User interface for operation and monitoring

6. Conclusions

The digital factory was proposed to support production preparation for various types of manufacturing system by IT tools. The production scenario can be reviewed by virtually execution in the digital factory. A construction method was also proposed. The digital factory is constructed as a multi agent system by means of component's agents of the production lines. And concrete example of the digital factory configuration was shown. The proposed configuration methodology allows the system user to integrate generally common methodologies for production planning and their original know-hows for manufacturing on a computer system and to use it as an IT platform and tools. Furthermore, it becomes widely possible to review production scenarios using IT tools before the actual production when this digital factory is available as a Web service such as Cloud service and SaaS (Software as a Service). Not only big major companies but also small and medium-sized enterprises will then be able to easily use the digital factory because it does not require a high ICT investment. In addition, an already running production scenario can also be checked again.

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